

DescriptionMETHODS FOR TREATMENT OF MULTIPLE SCLEROSIS USING
PEPTIDE ANALOGUES OF HUMAN MYELIN BASIC PROTEIN

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Technical Field

The present invention relates generally to methods for treating multiple sclerosis by using peptide analogues of human myelin basic protein.

10 Background of the Invention

Multiple sclerosis (MS) is a chronic, inflammatory disease that affects approximately 250,000 individuals in the United States. Although the clinical course may be quite variable, the most common form is manifested by relapsing neurological deficits, in particular, paralysis, sensory deficits, and visual problems.

15 The inflammatory process occurs primarily within the white matter of the central nervous system and is mediated by T lymphocytes, B lymphocytes, and macrophages. These cells are responsible for the demyelination of axons. The characteristic lesion in MS is called the plaque due to its macroscopic appearance.

Multiple sclerosis is thought to arise from pathogenic T cells that somehow evaded mechanisms establishing self-tolerance, and attack normal tissue. T cell reactivity to myelin basic protein may be a critical component in the development of MS. The pathogenic T cells found in lesions have restricted heterogeneity of antigen receptors (TCR). The T cells isolated from plaques show rearrangement of a restricted number of $V\alpha$ and $V\beta$ gene segments. In addition, the TCRs display several dominant amino acid motifs in the third complementarity determining region (CDR), which is the major antigen contact site. All together, three CDR3 motifs have been identified in T cell clones known to recognize an epitope within amino acids 86-106 of myelin basic protein. These motifs were found in 44% of rearranged TCR sequences involving one particular $V\beta$ gene rearranged in T cells isolated from brain of two patients with MS.

30 A definitive treatment for MS has not been established. Historically, corticosteroids and ACTH have been used to treat MS. Basically, these drugs reduce the inflammatory response by toxicity to lymphocytes. Recovery may be hastened from acute exacerbations, but these drugs do not prevent future attacks or prevent development of additional disabilities or chronic progression of MS (Carter and Rodriguez, *Mayo Clinic Proc.* 64:664, 1989; Weiner and Hafler, *Ann. Neurol.* 23:211,

FOOTNOTES

1988). In addition, the substantial side effects of steroid treatments make these drugs undesirable for long-term use.

Other toxic compounds, such as azathioprine, a purine antagonist, cyclophosphamide, and cyclosporine have been used to treat symptoms of MS. Like
 5 corticosteroid treatment, these drugs are beneficial at most for a short term and are highly toxic. Side effects include increased malignancies, leukopenias, toxic hepatitis, gastrointestinal problems, hypertension, and nephrotoxicity (Mitchell, *Cont. Clin. Neurol.* 77:231, 1993; Weiner and Hafler, *supra*). Antibody based therapies directed toward T cells, such as anti-CD4 antibodies, are currently under study for treatment of
 10 MS. However, these agents may cause deleterious side effects by immunocompromising the patient.

More recently, cytokines such as IFN- γ and IFN- β have been administered in attempts to alleviate the symptoms of MS. However, a pilot study involving IFN- γ was terminated because 7 of 18 patients treated with this drug
 15 experienced a clinical exacerbation within one month after initiation of treatment. Moreover, there was an increase in the specific response to MBP (Weiner and Hafler, *supra*).

Betaseron, a modified beta interferon, has recently been approved for use in MS patients. Although Betaseron treatment showed some improvement in
 20 exacerbation rates (Paty et al., *Neurology* 43:662, 1993), there was no difference in the rate of clinical deterioration between treated and control groups (IFNB MS Study Group, *Neurology* 43:655, 1993; Paty et al., *supra*). Side effects were commonly observed. The most frequent of such side effects were fever (40%-58% of patients), flu-like symptoms (76% of patients), chills (46% of patients), mylagias (41% of patients),
 25 and sweating (23% of patients). In addition, injection site reactions (85%), including inflammation, pain, hypersensitivity and necrosis, were common (IFNB MS Study Group, *supra*; Connelly, *Annals of Pharm.* 28:610, 1994).

In view of the problems associated with existing treatments of MS, there is a compelling need for improved treatments which are more effective and are not
 30 associated with such disadvantages. The present invention exploits the use of peptide analogues which antagonize a T cell response to human myelin basic protein to effectively treat MS, while providing other related advantages.

Summary of the Invention

35 The present invention provides peptide analogues comprising at least 7 amino acids selected from residues 86 to 99 of human myelin basic protein in which

either L-lysine at position 91, L-threonine at position 95, or L-arginine at position 97 is altered to another amino acid. In one embodiment, L-lysine at position 91 is altered and one to three additional L-amino acids selected from residues 86, 87, 88, 95, 98 or 99 are altered to another amino acid. In a second embodiment, L-threonine at position 95 is altered and one to three additional amino acids selected from residues 86, 87, 88, 91, 98 and 99 or 86, 87, 88, 97, 98, and 99 are altered to another amino acid. In a third related embodiment, L-arginine at position 97 is altered and one to three additional amino acids selected from residues 86, 87, 88, 95, 98 or 99 are altered to another amino acid. The peptide analogues preferably contain double or triple alterations. In preferred aspects of the invention, the peptide analogues have altered residues 91, 95 or 97 to alanine and the additional amino acids are altered to the corresponding D-form amino acid.

In other embodiments, peptide analogues comprise at least seven amino acids selected from residues 86 to 99 of human myelin basic protein in which either L-lysine at position 91, L-threonine at position 95, or L-arginine at position 97 is altered to another amino acid, and in addition the N-terminal and C-terminal amino acids are altered in order to reduce proteolysis upon administration of the peptide analogue. In a preferred aspect, the N- and C-terminal amino acids are of the D-form.

In other embodiments, the peptide analogues comprise at least seven amino acids selected from residues 86 to 99 of human myelin basic protein in which either L-lysine at position 91, L-threonine at position 95, or L-arginine at position 97 is altered to another amino acid and in addition up to three other amino acid alterations are made. Any residue within 86-99 may be altered except that in a peptide analogue in which residue 91 is altered, residue 97 may not be altered. Likewise, in a peptide analogue in which residue 97 is altered, residue 91 may not be altered.

Other embodiments provide peptide analogues comprising at least seven amino acids selected from residues 86 to 99 of human myelin basic protein in which either L-lysine at position 91, L-threonine at position 95, or L-arginine at position 97 is altered to another amino acid. In preferred aspects, residue 91, 95 or 97 are altered to either alanine or the corresponding D-amino acid.

Further aspects of the present invention provide a pharmaceutical composition comprising a peptide analogue according to the embodiments set out above in which the peptide analogue is contained in a physiologically acceptable carrier or diluent.

Further aspects of the present invention provide methods of treating multiple sclerosis by administering to a patient a therapeutically effective amount of a pharmaceutical composition comprising a peptide analogue comprising at least seven

amino acids selected from residues 86 to 99 of human myelin basic protein in which residues 91, 95 or 97 are altered to another amino acid. Additionally, one to three additional amino acids may be altered or the N- and C-ends are altered to reduce proteolysis upon administration.

5 These and other aspects of the invention will become evident upon reference to the following detailed description and attached drawings. In addition, various references are set forth below which describe in more detail certain procedures or compositions. Each of these references are incorporated herein by reference in their entirety as if each were individually noted for incorporation.

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Brief Description of the Drawings

Figure 1 depicts DNA and predicted amino acid sequence for human myelin basic protein.

15 Figure 2 depicts the response of draining lymph node cells from Lewis rats immunized 9-10 days previously with MBP (87-99) to 10 μ M of MBP (87-99), medium, the unrelated peptide motilin, and six different MBP analogues. A, alanine; k, D-lysine; t, D-threonine; r, D-arginine.

20 Figure 3 is a graph displaying the proliferative response of the T cell line NBI to residue 91-substituted analogues of human myelin basic protein (87-99). Ten different substitutions were tested. The proliferative response of the rat T cell line in response to concentrations of peptide analogues ranging from 0 to 150 μ M was determined. The extent of proliferation is shown as counts per minute; standard errors of the mean were less than $\pm 10\%$. MOT, motilin, a peptide unrelated to MBP; MBP (87-99), human myelin basic protein residues 87-99; K, lysine; R, arginine; N, asparagine; H, histidine; L, leucine; S, serine; G, glycine; k, D-Lysine; E, glutamic acid; 25 F, phenylalanine; A, alanine.

30 Figure 4 is a graph displaying the proliferative response of the T cell line NBI to residue 95-substituted analogues of human myelin basic protein (87-99). Ten different substitutions were tested. The proliferative response of the rat T cell line in response to concentrations of peptide analogues ranging from 0 to 150 μ M was determined. The extent of proliferation is shown as counts per minute; standard errors of the mean were less than $\pm 10\%$. MOT, motilin, a peptide unrelated to MBP; MBP (87-99), human myelin basic protein residues 87-99; T, threonine; A, alanine; t, D-threonine; G, glycine; I, isoleucine; Y, tyrosine; Q, glutamine; S, serine; K, lysine; E, 35 glutamic acid; H, histidine.

Figure 5 is a graph displaying the proliferative response of the T cell line NBI to residue 97-substituted analogues of human myelin basic protein. Eleven different substitutions were tested. The proliferative response of the T cells to concentrations of peptide analogues ranging from 0 to 150 μ M was determined. The extent of proliferation is displayed as counts per minute. MBP 87-99, myelin basic protein (87-99); R, arginine; a, D-alanine; r, D-arginine; G, glycine; K, lysine; Q, glutamine; E, glutamic acid; T, threonine; L, leucine; F, phenylalanine; H, histidine; A, alanine.

Figure 6 is a graph illustrating the ability of peptide analogues of MBP to inhibit proliferation of rat T cells that are reactive to MBP. The proliferative response of draining lymph node cells from rats immunized with MBP (87-99) to 16.7, 50, or 150 μ M of each analogue, or 5 μ M of MBP (87-99) is displayed. Analogues were added in the presence of 5 μ M MBP (87-99). The extent of proliferation is shown as counts per minute. Controls consisted of MBP (87-99) only at 5 μ M and medium only. h88/A91 refers to a representative peptide analogue of MBP (87-99) with D-histidine at residue 88 and alanine at residue 91; h88/A91/p99 refers to another representative peptide analogue of MBP (87-99) with D-histidine at 88, alanine at residue 91, and D-proline at residue 99.

Figure 7 is a graph demonstrating the inhibition of EAE induction in Lewis rats following injection of MBP (87-99). Arrows indicate days that either PBS (control) or h88/A91 peptide analogue were administered. EAE was recorded as 0, no symptoms; 1, tail paralysis; 2, hind limb weakness; 3, hind limb paralysis; 4, hind and front limb paralysis.

Detailed Description of the Invention

Prior to setting forth the invention, it may be helpful to an understanding thereof to set forth definitions of certain terms that will be used hereinafter.

"Human myelin basic protein" ("MBP") refers to a protein found in the cytoplasm of human oligodendroglial cells. The nucleotide sequence and predicted amino acid sequence of human MBP are presented in Figure 1 (SEQ. ID Nos. ____ and ____). Although not depicted in Figure 1, different molecular forms of human myelin basic protein generated by differential splicing or post-translational modification are also within the scope of this invention.

"Peptide analogues" of myelin basic protein are at least 7 amino acids in length and contain at least one difference in amino acid sequence between the analogue and native human myelin basic protein, one of which is a difference at residue 91, 95 or

97. Unless otherwise indicated, a named amino acid refers to the L-form. An L-amino acid from the native peptide may be altered to any other one of the 20 L-amino acids commonly found in proteins, any one of the corresponding D-amino acids, rare amino acids, such as 4-hydroxyproline, and hydroxylysine, or a non-protein amino acid, such as β -alanine and homoserine. Also included with the scope of the present invention are amino acids which have been altered by chemical means such as methylation (*e.g.*, α -methylvaline), amidation of the C-terminal amino acid by an alkylamine such as ethylamine, ethanolamine, and ethylene diamine, and acylation or methylation of an amino acid side chain function (*e.g.*, acylation of the epsilon amino group of lysine).

"Residue 91," "residue 95," and "residue 97" (also called position 91, position 95, and position 97, respectively), refer to amino acids 91, 95, and 97 of human myelin basic protein as displayed in Figure 1 or the amino acid at a comparative position. More specifically, the numbering system for these residues relates to the amino acid position within the native human protein, regardless of the length of the peptide or the amino acid position within that peptide.

Peptide Analogues of Myelin Basic Protein

As noted above, the present invention provides peptide analogues comprising at least 7 amino acids selected from residues 86-99 of human myelin basic protein and including an alteration of the naturally occurring L-lysine at position 91, L-threonine at position 95, or L-arginine at position 97, to another amino acid. In one aspect, the peptide analogue includes additional alteration of one to three L-amino acids at positions 86, 87, 88, 91, 95, 97, 98 and/or 99 of human myelin basic protein as long as 91 and 97 are not both altered in the same peptide analogue. In another aspect, the peptide analogue additionally has the N-terminal and C-terminal residues altered to an amino acid such that proteolysis is reduced upon administration to a patient compared to a peptide analogue without these additional alterations. In a further aspect, the peptide analogue of MBP comprises at least seven amino acids selected from residues 86-99 and has one of the residues at position 91, 95 or 97 altered to an amino acid not present in native MBP protein. In addition to such single alterations, one to three additional alterations of residues 86 to 99 may be made, as long as residues 91 and 97 are not altered in the same peptide analogue.

The peptide analogues are preferably 7 to 16 amino acids, and usually not longer than 20 amino acids. Particularly preferred peptide analogues are 14 amino acids in length. Residues 91, 95, and 97, which are L-lysine, L-threonine, and L-arginine, respectively, in the native human protein, are the key residues. Within the

subject invention, analogues must have an amino acid other than L-lysine at position 91, an amino acid other than L-threonine at position 95, or an amino acid other than L-arginine at position 97.

As noted above, any amino acid alteration at position 91 is within the scope of this invention. Preferred peptide analogues include alteration of L-lysine to any one of the following amino acids: D-lysine, alanine, glycine, glutamic acid, phenylalanine, arginine, asparagine, histidine, leucine or serine. These amino acids include both conservative (similar charge, polarity, hydrophobicity, and bulkiness) and non-conservative amino acids. Although typically one might expect that only non-conservative amino acid alterations would provide a therapeutic effect, unexpectedly even conservative changes (e.g., arginine) greatly affect the function of the peptide analogue as compared to the native peptide. Such diversity of substitution is further illustrated by the fact that the preferred amino acids noted above are hydrophobic and hydrophilic, charged and uncharged, polar and non-polar.

In addition, any amino acid substitution at residue 95 is also within the scope of this invention. Preferred peptide analogues contain alterations of L-threonine to any one of the following amino acids: D-threonine, alanine, glycine, isoleucine, tyrosine, glutamine, serine, lysine, glutamic acid and histidine. Other preferred alterations are to non-conservative amino acids. Particularly preferred alterations are to alanine or D-threonine.

Similarly, any amino acid alteration at position 97 is within the scope of this invention. Preferred peptide analogues include alteration of L-arginine to D-alanine, D-arginine, glycine, lysine, glutamine, glutamic acid, threonine, leucine, phenylalanine, histidine or alanine. Other preferred alterations are to non-conservative amino acids. Particularly preferred alterations are to alanine and D-arginine.

In addition, in certain embodiments at least one other amino acid selected from residues 86, 87, 88, 95, 98, or 99 is altered. If two other amino acids are changed, one is preferably selected from residues 86, 87, or 88, and the other is selected from residues 98 or 99. Alternatively, up to three alterations at any positions may be made.

With these general considerations in mind, peptide analogues within the scope of the invention have an alteration of residue 91, residue 95, or of residue 97. One set of preferred peptide analogues have double alterations. In one embodiment, residue 91 is altered as noted above, residue 87 is altered to D-valine, residue 88 to D-histidine or residue 99 to D-proline. Similarly, in another embodiment, residue 97 is altered as noted above, and either residue 87 is altered to D-valine, residue 88 to

D-histidine or residue 99 to D-proline. In yet another embodiment, residue 95 is altered as noted above and residue 87 is altered to D-valine, residue 88 to D-histidine or residue 99 to D-proline.

A second set of preferred peptide analogues have triple substitutions. In one embodiment, residue 91 is altered to alanine, residue 87 is altered to D-valine or residue 88 is altered to D-histidine and residue 99 is altered to D-proline. In another embodiment, residue 97 is altered to alanine, residue 88 is altered to D-histidine and residue 99 to D-proline. In yet another embodiment, residue 95 is altered to alanine, residue 88 is altered to D-histidine and residue 99 to D-proline.

Peptide analogues may be synthesized by standard chemistry techniques, including synthesis by automated procedure. In general, peptide analogues are prepared by solid-phase peptide synthesis methodology which involves coupling each protected amino acid residue to a resin support, preferably a 4-methyl-benzhydrylamine resin, by activation with dicyclohexylcarbodiimide to yield a peptide with a C-terminal amide. Alternatively, a chloromethyl resin (Merrifield resin) may be used to yield a peptide with a free carboxylic acid at the C-terminus. Side-chain functional groups are protected as follows: benzyl for serine, threonine, glutamic acid, and aspartic acid; tosyl for histidine and arginine; 2-chlorobenzoyloxycarbonyl for lysine and 2,6-dichlorobenzyl for tyrosine. Following coupling, the t-butyloxycarbonyl protecting group on the alpha amino function of the added amino acid is removed by treatment with trifluoroacetic acid followed by neutralization with di-isopropyl-ethylamine. The next protected residue is then coupled onto the free amino group, propagating the peptide chain. After the last residue has been attached, the protected peptide-resin is treated with hydrogen fluoride to cleave the peptide from the resin, as well as deprotect the side chain functional groups. Crude product can be further purified by gel filtration, HPLC, partition chromatography, or ion-exchange chromatography.

Peptide analogues within the present invention should (a) compete for the binding of MBP (87-99) to MHC; (b) not cause proliferation of an MBP (87-99)-reactive T cell line; and (c) inhibit induction of experimental allergic encephalomyelitis (EAE) by MBP (87-99) in rodents.

Thus, candidate peptide analogues may be screened for their ability to treat MS by (1) an assay measuring competitive binding to MHC, (2) an assay measuring a T cell proliferation, and (3) an assay assessing induction inhibition of EAE. Those analogues that inhibit binding of the native peptides, do not stimulate proliferation of MBP-reactive cell lines, and inhibit the development of EAE by native

human MBP (87-99), are useful therapeutics. Although not essential, a further safety assay may be performed to demonstrate that the analogue does not itself induce EAE.

- Binding of peptides to MHC molecules may be assayed on whole cells. Briefly, Lewis rat spleen cells are cultured for 3 hours to allow adherent cells to stick to polystyrene petri dishes. Non-adherent cells are removed. Adherent cells, which contain cells expressing MHC class II molecules, are collected by scraping the dishes. The binding of peptide analogues to cells is measured by a fluorescence assay. In this assay, splenic adherent cells are mixed with different concentrations of peptide analogues and incubated for 1 hour at 37° in a CO₂ incubator. Following incubation, biotin-labeled MBP (87-99) is added to the culture wells. The cells are incubated for another hour and then washed three times in medium. Phycoerythrin-conjugated or fluorescein-conjugated streptavidin is added along with a fluorochrome-labeled OX-6 or OX-17 monoclonal antibody, which reacts with rat MHC Class II I-A and I-E, respectively. The cells are washed twice before analysis by flow cytometry. Fluorescence intensity is calculated by subtracting the fluorescence value obtained from cells stained with phycoerythrin-streptavidin alone (control staining) from the fluorescence value obtained from biotin-labeled MBP (87-99) plus phycoerythrin-streptavidin (experimental staining). Staining without analogue establishes a 100% value. Percent inhibition is calculated for each analogue and expressed as IC₅₀ values. A peptide analogue with an IC₅₀ value of less than 100 µM is suitable for further screenings.

- Candidate peptide analogues are further tested for their property of causing or inhibiting proliferation of T cell lines. Two different assays may be used as alternatives. The first measures the ability of the analogue to cause proliferation of T cells in a direct fashion. The second measures the ability of the peptide analogue to inhibit proliferation of T cells induced by native MBP (87-99) peptide.

- In the direct proliferation assay, MBP (87-99) reactive T cell lines may be used as target cells. T cell lines are established from lymph nodes taken from rats injected with MBP (87-99). Lymph node cells are isolated and cultured for 5 to 8 days with MBP (87-99) and IL-2 as a source of T cell growth factors. Viable cells are recovered and a second round of stimulation is performed with MBP (87-99) and irradiated splenocytes as a source of growth factors. After 5 to 6 passages in this manner, the proliferative potential of the cell lines are determined. MBP-reactive lines are used in the proliferation assay. In this assay, T cell lines are cultured for three days with various concentrations of peptide analogues and irradiated, autologous splenocytes. After three days, 0.5-1.0 µCi of [³H]-thymidine is added for 12-16 hours.

Cultures are harvested and incorporated counts determined. Mean CPM and standard error of the mean are calculated from triplicate cultures.

As an alternative to the use of T cell lines as described above, draining lymph node cells from Lewis rats injected with MBP (87-99) may be used. Preferably, this assay is used in combination with the proliferation assay using T cell lines. Briefly, Lewis rats are injected subcutaneously with MBP (87-99) peptide in complete Freund's adjuvant. Nine to ten days later, draining lymph node cells are isolated and single-cell suspensions are prepared. Lymph node cells are incubated with various concentrations of peptide analogues for three days in a humidified air chamber containing 6.5% CO₂. After incubation, the cultures are pulsed with 1-2 µCi of [³H]-thymidine for 12-18 hours. Cultures are harvested on fiberglass filters and counted in a scintillation counter. Mean CPM and the standard error of the mean are calculated from data determined in triplicate cultures. Peptide analogues yielding results that are more than three standard deviations of the mean response with a comparable concentration of MBP (87-99) are considered non-stimulatory. Peptide analogues which do not stimulate proliferation at concentrations of less than or equal to 50 µM are suitable for further screenings.

The second or alternative assay is a competition assay for T cell proliferation. In this assay, antigen presenting spleen cells are first irradiated and then incubated with native MBP (87-99) peptide for 2-4 hours. These cells are then washed and further cultured with T cells reactive to MBP (87-99). Various concentrations of candidate peptide analogues are included in cultures for an additional 3 days. Following this incubation period, each culture is pulsed with 1 µCi of [³H]-thymidine for an additional 12-18 hours. Cultures are then harvested on fiberglass filters and counted as above. Mean CPM and standard error of the mean are calculated from data determined in triplicate cultures. Peptide analogues which inhibit proliferation to approximately 25% at a concentration of 50 µM or greater are suitable for further screening.

Candidate peptides that compete for binding of MBP (87-99) to MHC and do not cause direct proliferation of T cell line or can inhibit proliferation by MBP (87-99), are further tested for their ability to inhibit the induction of EAE by MBP (87-99). Briefly, 500 µg of MBP (87-99) is injected as an emulsion in complete Freund's adjuvant supplemented with heat killed *Mycobacterium tuberculosis* (H37Ra). Rats are injected subcutaneously at the base of the tail with 200 µl of the emulsion. Rats are divided into two groups. Approximately 2 days prior to disease induction (usually 10 days following injection of MBP (87-99)) rats are injected intraperitoneally either with PBS or peptide analogues in PBS. Animals are monitored for clinical signs

on a daily basis by an observer blind to the treatment protocol. EAE is scored on a scale of 0-4: 0, clinically normal; 1, flaccid tail paralysis; 2, hind limb weakness; 3, hind limb paralysis; 4, front and hind limbs affected. Peptide analogues injected at 5 mg/kg or less (approximately 1 mg per rat) are considered to inhibit the development of EAE if there is a 50% reduction in the mean cumulative score over seven days following onset of disease symptoms in the control group.

In addition, as a safety measure, but not essential to this invention, suitable peptide analogues may be tested for direct induction of EAE. As described in detail in Example 2, various amounts of peptide analogues are injected at the base of the tail of rats, and the rats examined daily for signs of EAE. A peptide analogue which is not considered to cause EAE has a mean cumulative score of less than or equal to 1 over seven days when 1 mg (5 mg/kg) in complete Freund's adjuvant is injected.

Treatment and Prevention of Multiple Sclerosis

As noted above, the present invention provides methods for treating and preventing multiple sclerosis by administering to the patient a therapeutically effective amount of a peptide analogue of human myelin basic protein as described herein. Patients suitable for such treatment may be identified by criteria establishing a diagnosis of clinically definite MS as defined by the workshop on the diagnosis of MS (Poser et al., *Ann. Neurol.* 13:227, 1983). Briefly, an individual with clinically definite MS has had two attacks and clinical evidence of either two lesions or clinical evidence of one lesion and paraclinical evidence of another, separate lesion. Definite MS may also be diagnosed by evidence of two attacks and oligoclonal bands of IgG in cerebrospinal fluid or by combination of an attack, clinical evidence of two lesions and oligoclonal band of IgG in cerebrospinal fluid. Slightly lower criteria are used for a diagnosis of clinically probable MS.

Effective treatment of multiple sclerosis may be examined in several different ways. Satisfying any of the following criteria evidences effective treatment. Three main criteria are used: EDSS (extended disability status scale), appearance of exacerbations or MRI (magnetic resonance imaging).

The EDSS is a means to grade clinical impairment due to MS (Kurtzke, *Neurology* 33:1444, 1983). Eight functional systems are evaluated for the type and severity of neurologic impairment. Briefly, prior to treatment, patients are evaluated for impairment in the following systems: pyramidal, cerebella, brainstem, sensory, bowel and bladder, visual, cerebral, and other. Follow-ups are conducted at defined intervals. The scale ranges from 0 (normal) to 10 (death due to MS). A decrease of one full step

defines an effective treatment in the context of the present invention (Kurtzke, *Ann. Neurol.* 36:573-79, 1994).

Exacerbations are defined as the appearance of a new symptom that is attributable to MS and accompanied by an appropriate new neurologic abnormality (IFNB MS Study Group, *supra*). In addition, the exacerbation must last at least 24 hours and be preceded by stability or improvement for at least 30 days. Briefly, patients are given a standard neurological examination by clinicians. Exacerbations are either mild, moderate, or severe according to changes in a Neurological Rating Scale (Sipe et al., *Neurology* 34:1368, 1984). An annual exacerbation rate and proportion of exacerbation-free patients are determined. Therapy is deemed to be effective if there is a statistically significant difference in the rate or proportion of exacerbation-free patients between the treated group and the placebo group for either of these measurements. In addition, time to first exacerbation and exacerbation duration and severity may also be measured. A measure of effectiveness as therapy in this regard is a statistically significant difference in the time to first exacerbation or duration and severity in the treated group compared to control group.

MRI can be used to measure active lesions using gadolinium-DTPA-enhanced imaging (McDonald et al. *Ann. Neurol.* 36:14, 1994) or the location and extent of lesions using T₂-weighted techniques. Briefly, baseline MRIs are obtained. The same imaging plane and patient position are used for each subsequent study. Positioning and imaging sequences are chosen to maximize lesion detection and facilitate lesion tracing. The same positioning and imaging sequences are used on subsequent studies. The presence, location and extent of MS lesions are determined by radiologists. Areas of lesions are outlined and summed slice by slice for total lesion area. Three analyses may be done: evidence of new lesions, rate of appearance of active lesions, percentage change in lesion area (Paty et al., *Neurology* 43:665, 1993). Improvement due to therapy is established when there is a statistically significant improvement in an individual patient compared to baseline or in a treated group versus a placebo group.

Candidate patients for prevention may be identified by the presence of genetic factors. For example, a majority of MS patients have HLA-type DR2a and DR2b. The MS patients having genetic dispositions to MS who are suitable for treatment fall within two groups. First are patients with early disease of the relapsing remitting type. Entry criteria would include disease duration of more than one year, EDSS score of 1.0 to 3.5, exacerbation rate of more than 0.5 per year, and free of clinical exacerbations for 2 months prior to study. The second group would include

people with disease progression greater than 1.0 EDSS unit/year over the past two years.

Efficacy of the peptide analogue in the context of prevention is judged based on the following criteria: frequency of MBP reactive T cells determined by limiting dilution, proliferation response of MBP reactive T cell lines and clones, cytokine profiles of T cell lines and clones to MBP established from patients. Efficacy is established by decrease in frequency of reactive cells, a reduction in thymidine incorporation with altered peptide compared to native, and a reduction in TNF and IFN- α . Clinical measurements include the relapse rate in one and two year intervals, and a change in EDSS, including time to progression from baseline of 1.0 unit on the EDSS which persists for six months. On a Kaplan-Meier curve, a delay in sustained progression of disability shows efficacy. Other criteria include a change in area and volume of T2 images on MRI, and the number and volume of lesions determined by gadolinium enhanced images.

Peptide analogues of the present invention may be administered either alone, or as a pharmaceutical composition. Briefly, pharmaceutical compositions of the present invention may comprise one or more of the peptide analogues described herein, in combination with one or more pharmaceutically or physiologically acceptable carriers, diluents or excipients. Such compositions may comprise buffers such as neutral buffered saline, phosphate buffered saline and the like, carbohydrates such as glucose, mannose, sucrose or dextrans, mannitol, proteins, polypeptides or amino acids such as glycine, antioxidants, chelating agents such as EDTA or glutathione, adjuvants (*e.g.*, aluminum hydroxide) and preservatives. In addition, pharmaceutical compositions of the present invention may also contain one or more additional active ingredients, such as, for example, cytokines like β -interferon.

Compositions of the present invention may be formulated for the manner of administration indicated, including for example, for oral, nasal, venous, intracranial, intraperitoneal, subcutaneous, or intramuscular administration. Within other embodiments of the invention, the compositions described herein may be administered as part of a sustained release implant. Within yet other embodiments, compositions of the present invention may be formulated as a lyophilizate, utilizing appropriate excipients which provide stability as a lyophilizate, and subsequent to rehydration.

Pharmaceutical compositions of the present invention may be administered in a manner appropriate to the disease to be treated (or prevented). The quantity and frequency of administration will be determined by such factors as the condition of the patient, and the type and severity of the patient's disease. Within

particularly preferred embodiments of the invention, the peptide analogue or pharmaceutical compositions described herein may be administered at a dosage ranging from 5 to 50 mg/kg, although appropriate dosages may be determined by clinical trials. Patients may be monitored for therapeutic effectiveness by MRI, EDSS, and signs of clinical exacerbation, as described above.

The following examples are offered by way of illustration and not by way of limitation.

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EXAMPLE 1

Preparation of Peptides

The peptides were synthesized by solid phase methodology on a peptide synthesizer (Beckman model 990). Peptides with an amidated carboxyl-terminus were prepared with a p-methylbenzhydrylamine resin (MBHA resin); for peptides with a free carboxyl-terminus, a Merrifield resin coupled with the appropriately protected amino acid was used. Both resins were obtained from Bachem Fine Chemicals (Torrance, CA). Derivatized amino acids (Bachem Fine Chemicals) used in the synthesis were of the L-configuration unless specified otherwise, and the N-alpha-amino function protected exclusively with the t-butyloxycarbonyl group. Side-chain functional groups were protected as follows: benzyl for serine, threonine, glutamic acid, and aspartic acid; tosyl for histidine and arginine; 2-chlorobenzoyloxycarbonyl for lysine and 2,6-dichlorobenzyl for tyrosine. Coupling of the carboxyl-terminal amino acid to the MBHA resin was carried out with dicyclohexylcarbodiimide and the subsequent amino acids were coupled with dicyclohexylcarbodiimide according to Ling et al. (*Proc. Natl. Acad. Sci. USA* 81:4302, 1984). After the last amino acid was incorporated, the t-butyloxycarbonyl protecting group was removed and the peptide-resin conjugate treated with a mixture of 14 ml hydrofluoric acid (HF), 1.4 ml anisole, and 0.28 ml methylethyl sulfide per gram of resin conjugate at -20°C for 0.5 hr and at 0°C for 0.5 hr. HF was removed in vacuum at 0°C, and the resulting peptide and resin mixture was washed twice with diethyl ether and twice with chloroform and diethyl ether alternately. The peptide was extracted five times with 2 M acetic acid, and the extract lyophilized. The lyophilized product was first purified on a column of Sephadex G-25 fine (Pharmacia-LKB, Piscataway, NJ) developed in 30% acetic acid to remove the truncated fragments and inorganic salts (Ling et al., 1984). Next, peptides were further purified by CM-32 carboxymethylcellulose cation-exchange chromatography (Ling et

al., 1984). Final purification was achieved by partition chromatography on Sephadex G-25 fine (Ling et al., 1984). The synthetic product was characterized by amino acid analysis, mass spectrometric analysis, and reversed-phase HPLC.

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EXAMPLE 2

Immunizations and EAE induction

MBP peptide and peptide analogues were dissolved in phosphate-buffered saline (PBS) and emulsified with an equal volume of incomplete Freund's adjuvant supplemented with 4 mg/ml heat-killed *Mycobacterium tuberculosis* H37Ra in oil (Difco Laboratories, Inc., Detroit, MI). Rats were immunized subcutaneously at the base of the tail with 0.2 ml containing 500 µg of peptide in the emulsion and were monitored for clinical signs daily. EAE was scored on a scale of 0-4, as follows: 0, clinically normal; 1, flaccid tail; 2, hind limb weakness; 3, hind limb paralysis; 4, front and hind limbs affected.

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EXAMPLE 3

Long-term T cell lines

Antigen specific long-term T cell lines were derived using the method developed by Ben-Nun et al. (*Eur. J. Immunol.* 11:195, 1981). Lewis rats were injected with MBP (87-99) as described above. Nine to ten days later draining lymph node cells were cultured (10^7 /ml) for 5-8 days in stimulation medium together with 10-20 µM of the MBP (87-99) peptide and 15 µ/ml IL-2. After 5 to 8 days of culture, viable cells were collected after Ficoll-Hypaque separation and washed three times. These cells were recultured at 1×10^7 cells/ml in medium with 5×10^5 irradiated (3000 rad) autologous splenocytes as accessory cells and 10-20 µM of MBP (87-99). After 5 to 6 stimulation cycles, plates were screened by the ability of cells to proliferate in response to MBP (87-99). Positive lines were transferred to 24-well flat bottom plates and restimulated.

EXAMPLE 4

MHC binding assay

The ability of MBP peptides and peptide analogues to bind MHC was measured. An assay which characterizes the binding of peptides to MHC molecules on antigen presenting cells (APC) was employed (Mozes et al., *EMBO J.* 8:4049, 1989; Gautam et al., *PNAS* 91:767, 1994). Spleen cells were cultured in Dulbecco's modified Eagle's medium supplemented with 10% fetal bovine serum (Hyclone Laboratories, Logan, UT) in standard polystyrene petri dishes (100 x 15 mm) in a 37°C incubator containing 6.5% CO₂ for 3 hours. Thereafter, non-adherent cells were removed, and the plates were washed three times with PBS. Adherent cells were collected using a cell scraper. The binding of MBP (87-99) analogues was measured using a fluorescence assay. Briefly, 5 x 10⁵ splenic adherent cells in staining buffer (PBS containing 0.1% bovine serum albumin) were mixed with different concentrations ranging from 0-400 µM of MBP (87-99) analogues in individual wells of U-shape 96-well microculture plates and incubated for 1 hr at 37°C in a 6.5% CO₂ incubator. Following incubation, 10 µM of biotin-labeled MBP (87-99) was added to culture wells for 1 h. Cells were washed three times with the staining buffer. Phycoerythrin-conjugated or fluorescein-conjugated streptavidin (Becton Dickinson, San Jose, CA) was added as a second step reagent (1 µg/well) along with 1 µg/well of fluorochrome-labeled OX-6 or OX-17 monoclonal antibody (Pharmingen, San Diego, CA), which reacts with rat MHC class II I-A or I-E, respectively. The cells were washed twice before cytofluorographic analysis on a FACScan (Becton Dickinson). Fluorescence intensity for each sample was calculated by subtracting the fluorescence obtained from OX positive cells stained with phycoerythrin-streptavidin alone (control staining) from the fluorescence obtained from OX positive cells stained with biotin-labeled MBP (87-99) plus phycoerythrin-streptavidin. Percent inhibition was calculated for each analogue and expressed as IC₅₀ values.

The peptide analogue, h88/A91, which contains D-histidine at position 88 and alanine at position 91 competed as effectively as MBP (87-99) for MHC against MBP (87-99). At 200 µM, MBP (87-99) inhibited binding by 68.4% and h88/A91 inhibited binding by 67.64%.

EXAMPLE 5

Antigen-specific lymph node cell proliferation assay

Female Lewis rates, approximately six weeks old, were purchased from Harlan Sprague, Indianapolis, IN. MBP peptides were dissolved in phosphate-buffered saline (PBS) and emulsified with an equal volume of complete Freund's adjuvant (Difco Laboratories, Inc., Detroit, MI) supplemented with 2 mg/ml of heat-killed *Mycobacterium tuberculosis* H37Ra in oil (Difco). Rats were immunized subcutaneously in the base of the tail with 0.1 ml containing 100 µg of the peptide in the emulsion. Nine to ten days following immunization, rats were sacrificed, their draining lymph node removed and a single cell suspension made. Cells were resuspended to 5×10^6 cells per ml in stimulation medium containing Dulbecco's modified Eagle's medium (Gibco BRL, Gaithersburg, MD) supplemented with 2 mercaptoethanol (5×10^{-5} M), L-glutamine (2 mM), sodium pyruvate (1 mM), penicillin (100 µg/ml), streptomycin (100 µg/ml), and 1% normal rat serum.

For the assay, 100 µl of the lymph node cell suspension was added to 96-well flat-bottom wells in the presence of an equal volume of medium containing 10 µM of various peptides (including: motilin as a negative control; MBP87-99; medium only or alanine or D-amino acid substituted at position 91, 95, or 97). Cultures were then incubated at 37°C in humidified air containing 7.5% CO₂. After 3 days of incubation, 1.0 µCi of tritiated thymidine (20 Ci/mM; New England Nuclear) was added to each well and the plates reincubated for an additional 12-16 hours. The plates were then harvested with a Matrix filtermate harvester (Packard) and counted using an Automatic Direct Beta Counter (Packard). Mean cpm and the standard error of the mean were calculated from triplicate wells.

As seen in Figure 2, MBP (87-99) stimulated lymph node cells in contrast to the peptide analogues. Alanine alterations at positions 95 and 97 and D-amino acid alterations at residues 91, 95, and 97 failed to stimulate cells above the control peptide, motilin.

EXAMPLE 6

Antigen-specific T cell line proliferation assays

Assays for the antigen-specific proliferation assay of T cell lines were performed in 96-well flat bottom microtiter plates as described (Zamvil et al., 1985;

Offner et al., 1992; Gold et al., 1992). T cell lines were established as described in Example 3. An initial 1:10 dilution of a 1.5 mM stock solution of MBP or the peptide analogues were added into tissue culture medium. The samples were diluted by three-fold serial dilutions (final volume 100 μ l). The responding continuous T cell lines were resuspended to 4×10^5 cells per ml and 50 μ l aliquots added to each well (5×10^4 cells per well). Approximately 1×10^6 irradiated (3000R) splenocyte feeder cells were also added to each well. Cultures were then incubated at 37°C in humidified air containing 7.5% CO₂ for 3 days. Twelve to sixteen hours prior to harvesting, 0.5-1.0 μ Ci of [³H]-thymidine (20 Ci/mM; New England Nuclear) was added to each well and the cultures reincubated. Plates were then harvested with a Matrix filtermate harvester (Packard) and counted using an Automatic Direct Beta Counter (Packard). Mean cpm and the standard error of the mean were calculated from triplicate wells.

As can be seen in Figures 3, 4, and 5 a peptide analogue with any substitution of position 91, 95, or 97 failed to stimulate proliferation of a MBP (87-99)-reactive T cell line. The effect was dramatic as even 150 μ M of peptide analogue was 1 to 2 logs less effective at causing proliferation.

EXAMPLE 7

Antagonism of T cell proliferation assay

T cell antagonism was detected in a prepulsed proliferation assay as described by De Magistris et al. (*Cell* 58:625, 1992) with minor modifications. Antigen presenting spleen cells were γ -irradiated (3000 rad) and incubated with shaking at a concentration of 10^7 cells/well with 0.2-2.0 μ M of the native peptide MBP (87-99) in stimulation medium in 10 ml tissue culture plates for 2.5 hours at 37°C in humidified air containing 6.5% CO₂. Spleen cells were then washed and re-cultured at a concentration of 5×10^5 cells/well in U-shape 96-well microculture plates together with 5×10^4 resting MBP (87-99) reactive T cells. Various concentrations of antagonist peptides, ranging from 5-150 μ M, were added for an additional 72 hours. Each well was pulsed with 0.5-1 μ Ci of [³H]-thymidine (specific activity 10 Ci/mmol) for the final 12-16 hours. The cultures were then harvested on fiberglass filters and the proliferative response expressed as CPM \pm SEM.

The data presented in Figure 6 demonstrates that the double altered peptide analogue, h88/A91, and the triple altered peptide analogue, h88/A91/p99, significantly inhibited proliferation of a MBP reactive T cell line. The triple altered

analogue caused inhibition at 50 μ M and higher concentration, while the double altered analogue caused inhibition at 150 μ M.

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EXAMPLE 8

Treatment of 87-99 Induced EAE in Lewis Rats

Female Lewis rats, which were 6-8 weeks old, were injected with 500 μ g of MBP (87-99) in CFA containing 500 μ g of *Mycobacterium tuberculosis* at the base of the tail in 200 μ l volume. Rats were divided in groups of 5. The control group received 0.5 ml of PBS and the treatment group received the h88/A91 peptide analogue (1 mg/0.5 ml PBS) intraperitoneally, twice, on days 9 and 10 after immunization. Animals were monitored for disease symptoms on a daily basis. EAE was recorded on the following scale: 0, no symptoms; 1, tail paralysis; 2, hind limb weakness; 3, hind limb paralysis; 4, hind and front limbs affected.

Data from two different experiments was obtained as mean cumulative score of 5 animals (Figure 7). Untreated control animals went on to develop high level of disease whereas h88/A91 analogue of the MBP peptide 87-99 was effective in preventing significantly the development of EAE in two experiments. Though the analogue was given just before the onset of overt symptoms, it was able to arrest the development of EAE.

EXAMPLE 9

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Induction of EAE by Peptide Analogue

The ability of peptide analogues to cause EAE is assessed *in vivo*. Rats were injected with MBP (87-99) or h88/A91 peptide analogue as described in Example 2. Animals were monitored daily for evidence of EAE. Rats receiving MBP (87-99) had 100% incidence (18/18 rats) of EAE with a mean maximum clinical score of 2.4 ± 0.2 . In contrast, 0/12 rats receiving the peptide analogue h88/A91 had EAE. Therefore, this peptide analogue does not induce EAE.

From the foregoing, it will be evident that although specific embodiments of the invention have been described herein for the purpose of illustrating the invention, various modifications may be made without deviating from the spirit and scope of the invention.